Gamoto-1
User's Manual

Gamatronix Motor Controller
Integrated PID Servo Motor Controller/Driver

User's Manual: Rev U

Documents the following versions:
Firmware through rev 21
MotoView Software v. 1.0.14 and later
PCB Hardware rev. E, F

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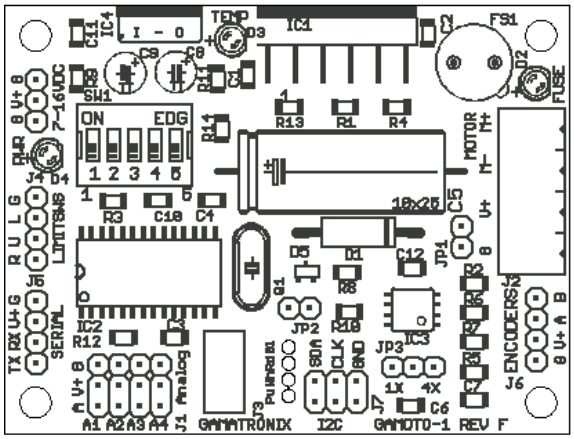
Gamatronix

Gamoto

Integrated PID Servo Motor Controller / Driver

Gamoto Feature Summary:



- 12 – 55 VDC Motor Voltage
- 7 – 16 VDC Logic Voltage input
- Integrated 3A continuous / 6A peak H-Bridge motor driver
- Trapezoidal Trajectory processing, for precise control of position, velocity, and acceleration
- Step + Direction pulse inputs, to work with stepper motor driver software
- R/C Pulse input, to work with Remote Control radios, hobby servo systems
- 1X and 4X quadrature encoder decoding
- I^2C slave interface, for motor control by an external I^2C
- Serial interface, 9600,19200, or 115200 baud
- Cricket Bus interface, for use with Handy Cricket control bus products
- Removable motor power fuse, with fuse fail indicator
- On-board flash memory to store parameters
- Analog reading of real-time motor current
- Limit switch interface to add optional upper limit, lower limit, and home switch inputs
- Expansion port with four analog input pins available for general purpose analog readings.

1. Overview

The Gamatronix Gamoto is an integrated module that includes a PID (Proportional, Integral, and Derivative) control chip, a motor driver, and quadrature encoder interface / conditioning circuitry, step/direction pulse input circuit, and an R/C Pulse capture circuit. A complete motor control system would include the Gamoto, a motor, power supply, and a quadrature encoder or analog potentiometer for position feedback. The Gamoto can also be used in direct power mode (open loop), in which case the position feedback is not necessary.

The host processor can communicate with the Gamoto in any one of three ways: Serial, I^2C, or Cricket Bus. Serial communication uses a simple binary-based protocol with a header and checksum, to reduce errors. As an I^2C slave device, the Gamoto accepts read and write commands to its internal registers, as well as some special commands, allowing full control over the Gamoto. Maximum speed is 400 kHz.

The third communication option is the Cricket Bus. This is a one-wire serial type of

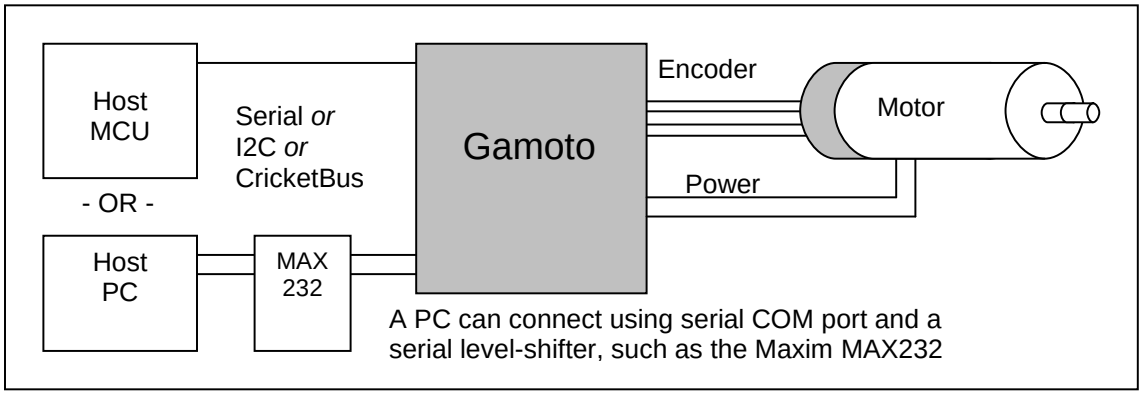
interface, similar to I^2C, but using only one signal line, plus power and ground. This bus is designed with Handy Cricket devices (www.handyboard.com/cricket), but since it is an open protocol, any host controller can implement this bus and use it to communicate with the Gamoto.

1.1 Technical Specifications

Processor	PIC16F876, 20 MHz
H-Bridge	LM18200 DMOS Quad H-Bridge
Motor Voltage input	12-55 VDC
Motor Current output	3A continuous, 6A peak
Logic Voltage input	7-16 VDC
Position Registers	32-bit signed, with 8-bit fraction
PID Constant Registers	16-bit signed
PWM Resolution	10-bit resolution
PWM Frequency	19.54 kHz
Trajectory Storage	6 trajectories storable in non-volatile flash
Analog inputs	4 user analog inputs, 10-bit resolution + 1 for motor current
Digital inputs	Upper limit, Lower limit switches, interlocks motion
Over-current protection	5A replaceable fuse, with LED indication of failure
Over-temp protection	Over-temp LED, auto-shutdown H-bridge
Encoder inputs	Filtered, up to 254,000 counts/sec
Parameter storage	Key parameters stored in non-volatile flash
Serial Interface	9600 or 19200 baud, serial command protocol
I2C Interface	Operates as an I2C slave, with command protocol
Cricket Bus interface	Complies with Cricket device bus for use with Handy Cricket
R/C Pulse Capture	0-3ms pulse width, with configurable hi/low set points
Step + Direction inputs	5V Digital pulse capture, triggers on positive edge of Step pulse signal.

1.1 Typical Application

Shown below is a block diagram of a typical application.



2. Operational Modes

The Gamoto can be operated in any of several operational modes. The mode setting can be changed "on-the-fly," by the host, during operation, or the power-on default mode can be customized, allowing it to always power up in the desired mode. For details of the actual Mode registers, see section xx. The various modes are outlined below.

2.1 Position Mode

Mode Register = 00000001 (0x01)

This is the default mode, in which the motor drives to the set position (stored in the setPosition register). On power-up, the setPosition is 0, and actual position (mPosition) is 0, so the motor will not move. However, if it is disturbed or pushed one way, it will drive to return to the target position. The PID algorithm (see Theory of Operation section) determines the power sent to the motor. In the windows control software, there is an interactive mode that demonstrates position control based on mouse movements.

2.2 Power Mode

Mode Register = 00010001 (0x11)

Enabled by setting PwrMode bit of Mode register. This mode is the simplest to use and to understand. In this mode, a raw motor power number is sent to the Gamoto, as a percentage of power desired to send to the motor. This register, mPower, is a signed 8-bit number, and can range from –128 to +127. (0 = 0% power, 127 = 100% forward, -128 = 100% backwards). In this mode the encoders are ignored, so in fact encoders are not necessary. However, if encoders are connected, then the current position and velocity can be read from the internal registers while the motor is running.

2.3 Velocity Mode

Mode Register = 0000101 (0x05)

Enabled by setting the VelMode bit of the Mode register. This mode allows easy control of

motor velocity, while still tracking the absolute position. When this mode is set, the value in register SetVelocity is used as a velocity target. Setting SetVelocity = 0 causes the motor to stop. SetVelocity is a signed 16-bit register, and the lowest 8 bits are fractional. The actual value to use for a given velocity depends upon your encoder resolution, so this must be found by trial and error.

The actual algorithm for this mode is as follows: SetVelocity is added to the target setPosition register every control cycle. This means the target position is always changing, but at a constant rate, leading to a constant average velocity. Be aware that if the motor is slowed by an obstacle, and then freed, it may temporarily speed up to "catch up" to the moving position target. This leads to an accurate *average* velocity, but not always the most stable instantaneous velocity.

2.4 Trajectory Mode

Mode Register = 0000011 (0x03)

Enabled by setting the TrajMode bit of the Mode register. This mode causes the Gamoto to immediately begin following the pre-set trajectory that has been stored in the trajectory registers.

2.4.1 Trajectory Stop

Mode Register = 0001011 (0x0B)

Enabled by setting the StopGrace bit of the Mode register, this allows the host to prematurely stop a trajectory in progress, but rather than suddenly stopping the motor, the motor is gracefully decelerated at the rate specified by the original trajectory. This is useful when the distance to travel is not known ahead of time, or an event triggers a necessary, but not urgent, stop. Note this requires Trajectory Mode to be enabled, and Velocity Mode disabled. If there is no trajectory currently active, setting this mode will have no effect.

2.5 Homing Mode

Mode2 Register = 00000001 (0x01)

This mode is normally disabled. Enabled by setting bit 0 of the Mode2 register, this mode allows an external home switch to clear the position register and stop the motor automatically. It changes two of the analog pins to digital pins (Analog pins 2 and 4), and uses Analog channel 4 (Connector J1, pin A4) as a home switch input. Normally high (you need to supply a pull-up resistor of 1K-50K), when pulled low while in Velocity mode, the position registers are cleared, Velocity is set to 0, and the mode will change to Position mode, stopping the motor.

The second converted digital channel, A2, is not used for this homing feature, and will still read analog values, even though it is configured as a digital pin.

2.6 MotionDone Enable

Mode2 Register = 00000010 (0x02)

This option is normally disabled. Enabled by setting bit 1 of the Mode2 register, this option turns one of the analog pins (A2) into an output, and uses it to signal when a motion profile has been completed (A2 goes high). This can be used as an interrupt to an external MCU or other control system, in place of polling the Mode register to detect when a motion is

complete. As with the Homing mode, pin A4 becomes a digital pin, but is still able to read analog input voltages.

2.7 SerialShare Enable

Mode2 Register = 00000100 (0x04)

This option is normally disabled. It allows you to connect up to 8 Gamotos to the same serial TX and RX lines, with no additional hardware other than a 10K pull-up resistor, which may be needed in some cases. When this bit is set, the Gamoto allows the TX line to float when it's not being used. Since each Gamoto only replies to messages addressed to it (by the correct header/DIP switch combination), then only the proper Gamoto will reply. Since the TX line is floating when not in use, a 10K pull-up resistor is recommend, if not already included in your serial transceiver or MCU.

2.8 115200 Baud Rate

Mode2 Register = 00001000 (0x08)

This option enables serial communication at 115200 baud, regardless of the dip switch settings for baud rate (9600/19200). Note that if you set this mode bit via a serial command, the response will come back at the current baud rate – it will not change to 115200 until you reset the Gamoto, either manually or with a reset command.

2.9 Step + Direction Pulse Inputs

Mode2 Register = 00010000 (0x10)

This option enables command of the motor via Step and Direction signals, similar to a stepper motor driver. This allows you to use existing stepper motor driver software, for example in CNC applications, to control your DC servo motor. The Step signal connects to J4 Pin 2 (Normally the Lower Limit switch input) and the Direction signal connects to J4 pin 3 (Normally the Upper Limit switch input). The limit switches are of course disabled while in this mode.

If the Direction signal is high, then each rising edge of the Step signal will jog the motor one count forward (setPosition gets incremented). If the direction signal is low, the setPosition register gets decremented.

StepSize Register (Address = 0xB3, or 179 decimal)

If you want each step pulse to jog more than one count, use the StepSize register to set the step size to something larger than 1. For example, if StepSize = 10, then each incoming step pulse will jog the motor to (mPosition + 10).

2.10 Analog Feedback Mode

Mode2 Register = 00100000 (0x20)

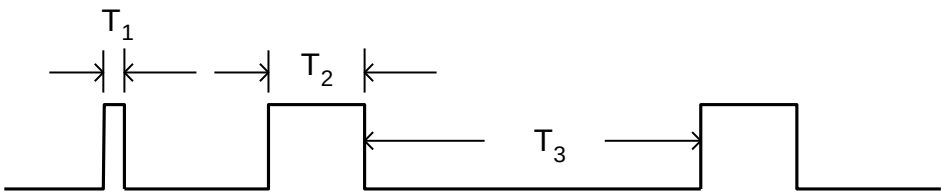
This mode allows Analog Channel 1 to be used as the position feedback, rather than quadrature encoder signals. This makes it easier to convert a simple motor to a servo, without the need for a costly quadrature encoder. The 0-1023 signal is fed directly to the mPosition register, and the encoder inputs are ignored.

2.11 R/C Pulse Input Mode

Mode2 Register = 01000000 (0x40)

This mode allows the Gamoto to accept standard R/C (Remote Control) input pulses to command the motor set point. These R/C pulses are generally in the range of 1ms – 2ms wide pulses, repeated every 20ms. The Gamoto accepts any pulse in the range of 0.2ms to 3ms, and the repeat rate is not important.

To configure the low and high pulse range and low and high desired set points, use the MotoView R//C Pulse configuration dialog, under the Tools menu. This dialog also shows the real-time pulse width being received, so it's handy for debugging your R/C equipment.



R/C Pulse Timing Requirements:

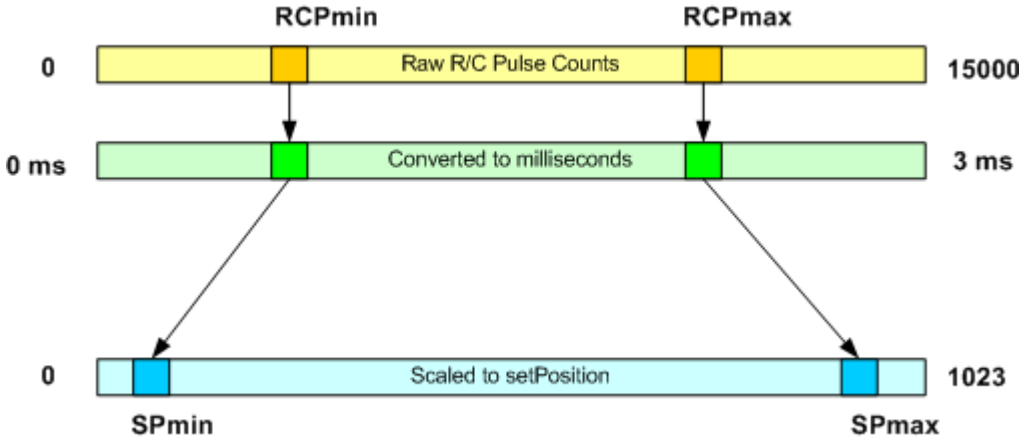
T1: Minimum pulse width is 0.2ms. Any smaller pulses will be rejected as noise.

T2: Normal pulse range is 0.2ms to 3.0ms. Max and min are settable via MotoView.

T3: Time between pulses must be at least 20 usec (0.020ms). There is no maximum. If the signal is lost, the set point will remain at the set point given by the last valid signal.

Note that in the current firmware version, when using R/C Pulse mode, you must also enable Analog Feedback mode.

To set up this feature, you need to set the following key parameters: RCPmin, RCPmax, SPmin, and SPmax. These parameters are described by the diagram below. Any R/C Pulse that is shorter than the RCPmin value (but greater than 0.2ms) will be result in a set point of SPmin. Similarly, a pulse larger than RCPmax will result in a set point of SPmax.



If we take an example, let's say you connect your R/C radio receiver to the Gamoto, open

the MotoView R/C config dialog, and look at the Raw R/C pulse counts. If you're getting values from say 4412 to 9762, then you could set RCPmin to 4500, and RCmax to 9700. Values outside of this range will get clipped to the max and min values.

Now you need to look at your potentiometer, and see what values you get for feedback. If your analog1 channel is showing values from 8 to 1019, then you could set SPmin to 10 and SPmax to 1015. You wouldn't want to set the min/max values outside of your actual range, or else you could reach the mechanical limit of your motor motion, and the motor would still be trying to drive.

2.12 PWM Modes

There are two available modes for controlling the power to the motor. Both use Pulse Width Modulation (PWM), which is a digital way of delivering a range of power to a device. Depending upon the motor design and application, it may be desirable to use one mode over another.

2.12.1 Sign-Magnitude

Sign-Magnitude is the default mode. This method requires that two signals be sent to the H-bridge: direction (Sign), and Magnitude. The Magnitude is always positive, and the direction changes depending on which way the motor is to be driven.

The Magnitude signal is a square wave with a fixed base frequency of 19.2 kHz, and varying duty cycle, from 0 to 100%, corresponding to 0 and 100% power delivered to the motor.

The Sign, or direction signal, is a digital high for clockwise rotation, and low for counter-clockwise motion.

2.12.2 Locked Anti-Phase

To enable Locked Anti-Phase (LAP) mode, set the LAP PWM bit in the Mode byte. Any time you change this bit, you need to save to Flash, then power cycle before it takes effect.

In LAP mode, direction and magnitude are combined into one signal. The "zero power" condition is represented by a 50% duty cycle. Full forward is 100% duty cycle, and full backward is 0% duty cycle. The reason for this behavior is that this pin is connected to the Direction input of the H-bridge, so that at 50% power, the motor is actually reversing direction constantly, which averages out to zero net power.

The other pin on the H-bridge that is normally used for PWM input is now used to enable or disable the motor.

The advantages and disadvantages of these PWM modes have been much debated in the motor control community. If you don't have an opinion, use the default Sign Magnitude mode. If you have a very free-spinning motor and would like more of a braking effect when slow or stopped, then you should try LAP mode.

3. Braking behavior

The LMD18200 Dual H-Bridge chip has a braking feature that, in the case of the Gamoto, is controlled by one bit (the "Brake" bit) in the Mode byte. When the Brake bit is set, the Brake pin on the bridge goes high. When the Brake bit is clear, the Brake pin goes low.

The first confusing point is that this type of "braking" usually does not stop a motor, and is sometimes a barely noticeable effect. It works by effectively shorting the motor coil leads

together. With some motors this causes a strong resistance to spinning, and other motors just seem sluggish. It's best to think of it as a way to reduce the amount of "coasting" or free-wheeling after a controlled move.

The second confusing part of the braking behavior is the way that the H-Bridge has implemented the brake. The data sheet states that to assert the brake, you not only need to set the Brake pin high, but also set the PWM input high. The PWM input normally tells the motor to turn on! So in the case of the Gamoto, you would need to turn on the Brake bit of the Mode byte, then command the motor to go at full power (set PwrMode of Mode byte, then set mPower=127), in order to activate the brake. This actually works – the motor does not turn, and has a noticeable resistance to turning in this condition. But there is a better way.

The third confusing part of the behavior actually allows a more convenient way to use the brake. According to the H-bridge datasheet, if the brake pin is Low (disabled) while the PWM pin is low (no command for power), then the braking is actually ON. This means that during normal operation, when you signal zero power to the motor, the braking is activated. This actually makes sense, because if you want zero power, you generally want to stop. If, for some reason, you want to stop and coast, then you ask for zero power, and then turn ON the Brake bit. Note that as long as the Brake bit is on, it cannot be controlled by the Gamoto, so if it slips away from its setPosition, it will not drive back to set point until the Brake bit is turned off.

Bottom line: Don't worry about the Brake. For most cases, you won't ever need to set it or read it or understand it. The one exception is the case where you really want to free-spin your motor with no power. In this case, send zero power and turn on the brake bit.

4. Theory of Operation

The Gamoto motor controller uses a PID (Proportional, Integral, and Derivative) algorithm to calculate how much power to deliver to the motor, and in which direction. This is not a new technique. It was developed in the 1960's, and is still the accepted standard today for fast, accurate motion control, as well as most other types of control systems.

The main equation has three major components, the sum of which equals the power to be delivered to the motor. The inputs to the equation are the set point ("setPosition" register), the actual position ("mPosition" register), and the three key constants, Kp, Ki, and Kd, the proportional, integral, and derivative constants, respectively.

We can calculate the error, "u," by subtracting the set point from the actual position:

(1) $u = mPosition - setPosition$

The Proportional component is straightforward:

(2) $Kp \times u$

The Integral component is calculated based on the integral over time of the error:

(3) $Ki \times \int u dt$

The Derivative component is calculated based on the differential the actual position over time, which in the case of motor control, is the same as the velocity ("mVelocity" register):

(4) $Kd \times mVelocity$

So the resulting equation is:

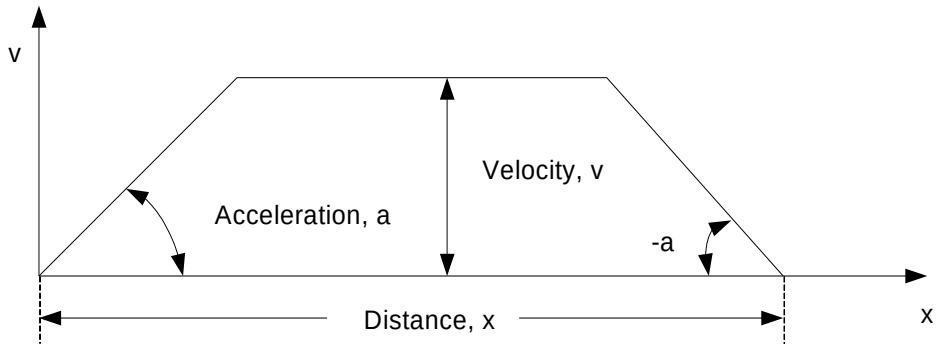
$$mPower = Kp \times u + Ki \times \int udt + Kd \times mVelocity$$

One more final scaling is performed, to allow the use of motors that cannot handle the full voltage of the power supply. For example, if you are using a six volt motor with a 12 Volt battery, you can set pwrLimit = 50% power, or 127. The final equation then, is:

$$mPower = [\, Kp \times u + Ki \times \int udt + Kd \times mVelocity \,] \times [\, pwrLimit / 255 \,]$$

4.1 Trajectory Control

As mentioned in the velocity mode section, velocity is controlled by continuously adding to the position set point. In the same manner, adding to the velocity set point can cause a constant acceleration. These techniques are combined, along with distance planning and deceleration, to create a Trajectory Move. The diagram below shows a normal trajectory move.



Given a desired distance, velocity, and acceleration, a move can be completed smoothly and accurately. You can create and test these trajectories easily, using MotoView. Once you decide a few trajectories that you will use in your application, you can store up to seven of them in flash. Or you can create them and run them on the fly.

To run a trajectory, the following steps are necessary:

- Write to the desired X, V, and A trajectory registers
- Write the corresponding trajectory number to the TrajNum register
- Set Mode to 0x03 to run the trajectory
- To determine when it's complete, you can poll the Trajectory Mode bit in the Mode byte. Or you can turn on MotionDone Enable (by setting Mode2, bit 1), and monitor pin A2 (on J1). This pin is normally low, and will go high when the motion is complete.
- The distance value is always a relative distance, to be added to the current position. When using trajectories, it's a good idea to follow these guidelines:
- For negative moves, use a negative x or negative v, but never use a negative acceleration.
- v/a should be an integer, especially for large values of v and/or a. For example, if v=5000 and a=1000, then after 5 cycles, v will become 5000, and will stop increasing. But if a=1100, then after 4 cycles, it will be 4400, and after 5 cycles, will overshoot to

5500, and then stop increasing. In the extreme case of v close to the maximum value (32767) and large values of a, then the velocity can roll over to a negative value.

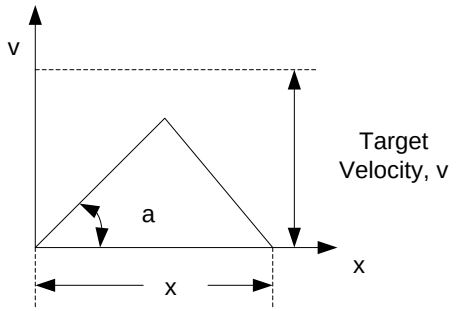
- If the maximum v is not fast enough, decrease dS.
- If the minimum v is not slow enough, increase dS.
- *Reminder: Changing dS will also affect the strength of the Kd term, in a linear fashion.*

Maximum values for trajectory variables:

Var	Length	Range
x	3 bytes, signed integer	-8388608 to 8388607
v	2 bytes, signed integer	-32768 to 32767
a	2 bytes, signed integer	0 to 32767

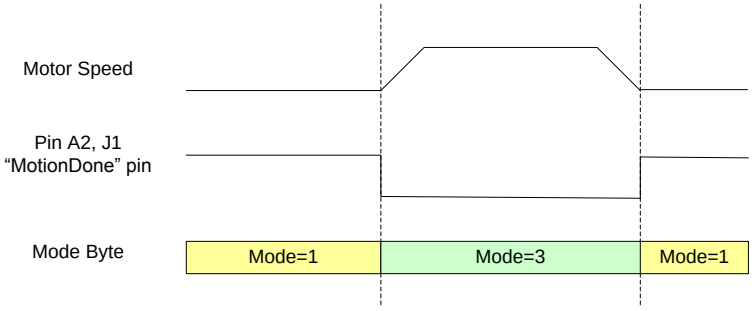
Special case: Short Trajectory

In the event that the distance specified is short, and acceleration is small, then the velocity may never be achieved. This is not a problem for the Gamoto, but it is good to be aware of this possibility. A diagram showing this situation is shown here:



Detecting the end of the trajectory:

This diagram shows a trajectory move, and how the Mode byte changes and the MotionDone pin signals the end of the trajectory, if MotionDone is enabled in the Mode2 byte:



NOTE: It's important to note that by "Trajectory Done" it means that the position setpoint (setPosition) has reached its target value, not that the actual position has reached the

target value. There are several reasons for this. The main reason is that there is no good way to tell if the position has been reached, i.e. what if it reaches it briefly, but then overshoots the position? What if it comes close, but due to the P,I,D settings, there is some steady-state error? How long should it "settle" at the destination before declaring it has arrived? If it never reaches, what should the timeout behavior be? All of these questions will have very different answers depending on the application, so we have left it to the user to decide. The idea is the user would implement this kind of use case:

- Distance is set to 10000 (default)
- Velocity is set to 5000 (default)
- Acc set to 10 (default)
- TrajMode is set to 1
- SetPosition increases
- Host program polls "Trajectory Done" bit, until it changes to 0 (now we know setPosition = 10000)
- Host position polls "Error" register (u0) until Error = 0, or |Error| < AcceptableLevel
- <insert timeout behavior, acceptable level window, etc. logic in this step>
- Now we know we have arrived at the destination

4.2 Units of Measurement

The units used to control and calculate the position, velocity, and acceleration are different than typical “real-world” units. To aid in the conversion to meaningful units, this section describes how to do the conversions.

Some basic definitions:

CPR = Counts per revolution (counts/rev). This is how many encoder counts for every complete revolution of your output shaft or wheel. To measure this value, run MotoView and show the Register View window. Display mPosition. Turn your output shaft one turn, and note how many counts have passed.

ORD = One Revolution Distance (inches/rev, feet/rev, etc.). This is the distance your device moves in one revolution, in the distance units of your choice. In the case of a wheel, it's the circumference of the wheel.

To = Period of Gamoto PID loop. This is a fixed constant, equal to 0.00051 seconds.

dS = Number of PID cycles to skip when updating velocity, Kd, and profile information. The factory default value is 10, but this is changeable by the user.

V = Velocity. This can be represented in many units, as shown below. The basic unit is the internal Gamoto units, which are in relation to the PID loop of the Gamoto.

4.2.1 Velocity Equations

$$\mathcal{V}\,(counts/sec) = \frac{\mathcal{V}}{256 * To * dS}$$

V (inches/sec) = V (counts/sec) * (ORD/CPR) (assuming ORD is in inches/rev)

V (miles/hour) = (V in inches/sec) * (5/88)

Example calculation:

We have a robot with 3" diameter wheels, driven by a motor with 19:1 gear reduction. The encoders have 250 counts/rev, and are attached to the motor, before the gear reduction.

First, the CPR of the **output shaft** = 250 * 19 = 4750 counts/rev.

The ORD = circumference of the wheel, or pi * D, or 3.14159*3 = 9.42 inches/rev

When using MotoView, we enter a set velocity = 8000, and dS=10. How fast is the motor going?

V = 8000 / (256*0.00051*10) = 6127.5 counts/sec

V = V (counts/sec) * (ORD/CPR) = 6127.5 * (9.42/4750) = 12.15 inches/sec

V = (V in inches/sec) * (5/88) = 12.15 * (5/88) = 0.69 miles/hour

4.2.2 Acceleration Equations

$$\mathcal{A}\,(cnts/sec^2) = \frac{\mathcal{A}}{256 * (To * dS)^2}$$

A (inches/sec^2) = A (cnts/sec^2) * (ORD/CPR)

A (relative to gravitational constant g) = A (inches/sec^2) / (12 * 32.2)

Example calculation:

If we continue the above example, let's find out how fast an acceleration setting of 20 will cause the robot to accelerate:

A (cnts/sec^2) = 20 / (256 * (.00051 * 10)^2) = 20 * 150.18 = 3003.65 cnts/sec^2

A (inches/sec^2) = 3003.65 * (9.42 / 4750) = 5.96 inches/sec^2

A (relative to g) = 5.96 / (12 * 32.2) = 0.015 g

4.2.3 Example Torque Calculation

Let's assume we are powering our robot with two motors capable of 20 oz-in of torque. What value should we use for the Gamoto acceleration setting? Assume our robot weighs 4 lbs, or 64oz.

First, since we have two wheels, we have 2 x 20 = 40 oz-in of torque available. Now, the definition of torque is force times distance:

Torque = 40 oz-in = (Force) x (Wheel Radius), so, solving for Force, F = T/r

Force = (40 oz-in) / (1.5 inches) = 26.7 oz = 1.67 lbf

So now we know the Force we want. How does this relate to acceleration?

F = ma (Newton's Law), so a = F/m

First we need to know the mass in lbm, which is equal to its weight divided by g:

m = 4 lbf = (4/32.2) = 0.124 lbm

a = (1.67 lbf) / (0.124 lbm) = 13.44 ft/ sec^2

a = (13.44 ft/sec^2) x (12 in/ft) = 161.3 in/ sec^2

Now we know the acceleration in in/sec^2 that we are shooting for. To summarize all of the above calculations, we can use this condensed expression:

$$A\ (in/sec^2) = \frac{24.15 * T}{W * r}$$

Where T = Total Torque in oz-in, W = Weight in pounds, and r = wheel radius in inches.

Now we need to use the acceleration equations backwards to deduce what we should use for our A setting.

$$A = \frac{A\ (inches/sec^2) * 256 * (To * dS)^2 * CPR}{ORD}$$

$$A = \frac{161.3\ (inches/sec^2) * 256 * (0.00051 * 10)^2 * 4750}{9.42}$$

$$A = 542$$

So now we know the maximum setting possible for use in our trajectories. Setting any value higher than this will exceed the capacity of our motors, and will result in high errors and overshoot.

Keep in mind that when using trajectories, the velocity you choose should be an even multiple of the acceleration. In this example, valid velocities include 5420, 8130, 11382, etc. Any even multiple of 542, that is within the bounds of valid velocities (-32768 to +32767).

5. Internal Registers

The host controls the Gamoto by writing to and reading from various internal registers. Each section below describes the name, address, and purpose of each internal register. Where applicable, an R, W, or R/W is shown, indicating whether the register is Read-only, Write-only, or Read/Write, respectively. **Note that registers in locations 34 - 44 can be changed and stored to flash, to allow different power-on conditions.**

5.1 Command Registers

Almost everything you need to do to control the Gamoto can be done by reading or writing to the internal registers. However, there are a few special cases of standalone commands, listed below, that require different treatment. Writing to any of these registers will execute the command. The data that is written is not important; in fact you don't need to write any data at all. Any write command to these registers will activate the command.

5.2 Register Memory Map

Note: All registers are stored with the LSB first, MSB at the highest address. Where noted, some registers have a fractional component.

DEC	HEX	Register	Len	Description
0	$00	FactoryRst	1	Writing to this special command register will cause all key registers (34 – 44) to be reset to factory default values. See Appendix A for factory default values. WARNING: This command takes about 300 ms to execute. If you execute this command during a trajectory move or while in velocity mode, you may notice a slight jerk or hesitation in motion. It is best not to issue this command while in velocity or trajectory mode.
1	$01	SaveParms	1	Writing to this special command register will save all key registers to flash. After this operation, these values will survive a power cycle. The key registers are locations 34 – 44, and all motion trajectory values. WARNING: This command takes about 300 ms to execute. If you execute this command during a trajectory move or while in velocity mode, you may notice a slight jerk or hesitation in motion. It is best not to issue this command while in velocity or trajectory mode.
2	$02	Reset	1	Writing to this special command register will reset the Gamoto, just as if it were power-cycled. As with all command registers, any dummy byte can be written to activate the command.
3	$03	SetHome	1	Writing to this special command register will set the mPosition and setPosition registers to zero, effectively making the current position “Home”. The current Mode is not changed.
34	$22	Kp	2	Kp is the proportional constant register, used to scale the overall response of the system. Kp is multiplied by the position error. Signed 16-bit number. Can range from –32768 to + 32767, but negative numbers should not be used for this register.
36	$24	Ki	2	Ki is the integral constant register, used compensate for steady-state error in the system. Ki is multiplied by the integral of the position error. Signed 16-bit number. Can range from –32768 to + 32767, but negative numbers should not be used for this register.
38	$26	Kd	2	Kd is the derivative constant register, used to compensate for overshoot in the system. Kd is multiplied by the derivative of the position error. Signed 16-bit number. Can range from –32768 to + 32767.
40	$28	iLimit	2	iL (integration Limit) is used to limit the maximum build-up of integral error. Prevents “integral windup” problems, when a long-lasting steady-state error causes excessive build-up of the integral term. Signed 16-bit number. Can range from –32768 to + 32767, but negative numbers should not be used for this register.
42	$2A	dS	1	Unsigned 8-bit number. Can range from 1 to 255. Setting this to 0 has the effect of setting dS = 256. Number of cycles over which average velocity is calculated. For higher resolution encoders, this number should be lower, to prevent overrun of actual motor velocity register (mVelocity). For low resolution encoders, increase this number. This is also used to trigger the update of the trajectory variables. A lower number updates more often.
43	$2B	Mode	1	8-bit number. Each bit enables or disables various modes. For a complete description, refer to section 3.1, Mode Register.

44	$2C	pwrLimit	1	8-bit number to limit maximum power delivered to the motor. Set to 0 for zero power to motor, 127 for 50% power, and 255 for 100% power. Normally set to 255. Use this to limit max voltage when using a lower-voltage rated motor. For example, using a 12V battery with a 6V motor, set this to 127, and the motor will never see more than the equivalent of 6 volts.
45	$2D	Mode2	1	8-bit number. Each bit enables or disables modes. For complete description, see section 3.2, Mode2 Register.
47	$2F	setPosition	3	24-bit signed integer. Can range from –8,388,608 to 8,388,607. This is the **target** position. The error term is the difference between **setPosition** and **mPosition**.
51	$33	mPosition	3	24-bit signed integer. Can range from –8,388,608 to 8,388,607. This is the actual motor position. The error term is the difference between setPosition and mPosition
54	$36	setVelocity	2	16-bit signed integer, specifying desired velocity. This number, divided by 256, is added to the target position, setPosition, every dS period. For example, if dS=10, then every 10^{th} control cycle, setVelocity/256 is added to setPosition.
57	$39	mVelocity	2	This is a signed 16-bit number that represents the actual motor velocity, totaled over several (dS) cycles. The velocity is calculated as the change in encoder counts in a given time period. To change the scaling of this number, dS can be adjusted. mVelocity is also the multiplier for Kd, used to calculate the derivative term for the control loop, so changing dS will have a direct effect on the strength of the derivative term.
59	$3B	trajectory	1	The trajectory register is used to choose which trajectory you would like to run. To run a given trajectory, first store the desired distance, velocity, and acceleration in one of the 7 trajectory register sets. Then specify which trajectory register set you want to run by writing to trajectory. Then turn on trajectory mode by writing the proper mode command to the Mode register.
60	$3C	mPower	1	Motor power. Signed 8-bit number. Used normally in open-loop mode (without encoders), or when you want manual control over actual voltage delivered to the motor. Setting mPower = 0 will cause motor to stop. Setting mPower = 64 will cause 50% forward power. Setting mPower = 127 will cause full forward power, setting mPower= -128 (128) will cause full reverse power. A setting of –64 (192) will cause 50% reverse power.
90	$5A	RCPraw	2	Raw R/C pulse counts. 5000 counts = 1ms. This holds the length of the last R/C pulse received. Only used while in R/C mode.
97	$61	u0	3	Error term. Signed 24-bit number. This is the difference between the target position (setPosition) and actual motor position (mPosition). Read this value to detect if an obstacle or friction is causing a large difference between the goal and actual position, or velocity.
178	$B2	version	1	Firmware version number. Integer from 1 to 255. Read only
179	$B3	StepSize	1	Number of steps to “jog” when step/dir input is enabled, and Gamoto receives a step pulse.
226	$E2	SPmin	2	setPosition Minimum. This is the minimum value that will be set by an incoming R/C pulse. Refer to the R/C mode description.
228	$E4	SPmax	2	setPosition Maximum. This is the maximum value that will be set by an incoming R/C pulse. Refer to the R/C mode description.
230	$E6	RCPmin	2	R/C Pulse minimum. This is the minimum pulse length accepted by the Gamoto. Shorter lengths will be clipped to this length. The units are in raw counts, 5000 counts = 1 ms.

232	$E8	RCPmax	2	R/C Pulse maximum. This is the maximum pulse length accepted by the Gamoto. Longer lengths will be clipped to this length. The units are in raw counts, 5000 counts = 1 ms.

5.3 Analog Registers

These registers are all two byte (16-bit) memory locations, but there is only 10 bits of resolution. The data is right-justified to the LSB, that is, the LSB is the first byte, and it contains the lower 8 bits, and the next byte contains the upper two bits of the analog value. The upper remaining bits are padded with zeros.

Example of register mapping for Analog0 register:

MSB			**LSB**							
<zero padding>	1	0	1	1	0	1	0	1	0	1
161 ($A1)			**160 ($A0)**							

This table shows the addresses for all of the analog registers. Note that Analog0 is a special case: it is tied to the motor current output signal from the H-Bridge.

DEC	HEX	Register	Len	Description
160	$A0	Analog0	2	This is wired directly to the H-Bridge, and provides a reading proportional to Motor current. Reading translates to approximately 186 counts / amp, with max reading of 1023 counts = 5.5 Amps
162	$A2	Analog1	2	Analog input 1. Scale is 0-5V, with 10-bit resolution, making the register minimum = 0, maximum = 1023.
164	$A4	Analog2	2	Analog input 2. Scale is 0-5V, with 10-bit resolution, making the register minimum = 0, maximum = 1023.
166	$A6	Analog3	2	Analog input 3. Scale is 0-5V, with 10-bit resolution, making the register minimum = 0, maximum = 1023.
168	$A8	Analog4	2	Analog input 4. Scale is 0-5V, with 10-bit resolution, making the register minimum = 0, maximum = 1023.

5.4 Motion Trajectory Registers

The motion trajectory registers are shown below. The all begin with LSB first as with all registers. The distance register is three bytes (24-bits), and the others are 2 bytes (16-bits). You can store up to six motion trajectories in this memory space, and they can be saved in non-volatile flash memory if desired (see the SaveParms command).

To calculate the address of a motion profile register (where n = 0 to 5):

```
X(n) = 180 + n*7

V(n) = 183 + n*7

A(n) = 185 + n*7
```

DEC	HEX	Length	Register	Description
180	$B4	3	X0	Relative distance for motion trajectory
183	$B7	2	V0	Velocity for motion trajectory
185	$B9	2	A0	Acceleration for motion trajectory
187	$BB	3	X1	Relative distance for motion trajectory
190	$BE	2	V1	Velocity for motion trajectory
192	$C0	2	A1	Acceleration for motion trajectory
194	$C2	3	X2	Relative distance for motion trajectory
197	$C5	2	V2	Velocity for motion trajectory
199	$C7	2	A2	Acceleration for motion trajectory
201	$C9	3	X3	Relative distance for motion trajectory
204	$CC	2	V3	Velocity for motion trajectory
206	$CE	2	A3	Acceleration for motion trajectory
208	$D0	3	X4	Relative distance for motion trajectory
211	$D3	2	V4	Velocity for motion trajectory
213	$D5	2	A4	Acceleration for motion trajectory
215	$D7	3	X5	Relative distance for motion trajectory
218	$DA	2	V5	Velocity for motion trajectory
220	$DC	2	A5	Acceleration for motion trajectory

5.5 Mode Register

The mode register is shown below. It is a one-byte register, and each bit serves a different function, as shown. Care must be taken to avoid setting incompatible bits, as not every combination is allowed. The allowable modes and combinations are described in the paragraphs below.

Register Name: **MODE** (Address 0x2B)

R/W 0	R 0	R/W 0	R/W 0	R/W 0	R/W 0	R/W 0	R/W 0
LAP PWM	Over-temp	Brake	PwrMode	StopGrace	VelMode	TrajMode	MpwrON
Bit 7	6	5	4	3	2	1	Bit 0

bit 7 Locked Anti-Phase PWM mode
1 = LAP mode
0 = Sign-Magnitude PWM mode
NOTE: To change PWM mode, you must first set/clear the bit, then save to Flash, then power-cycle the motor controller. This only required for this particular Mode bit.

bit 6 Over-temperature condition (READ-ONLY signal from H-bridge)
1 = Over-temp signal is active from H-Bridge. Motor is disabled, and setPosition is set to mPosition, so when condition clears, motor will not jump
0 = Normal condition

bit 5 Brake On
1 = Brake signal is being sent to H-Bridge
0 = Normal condition

bit 4 PwrMode
0 = Power Mode is Disabled. In this state, the PID loop operates normally, and the mPower register is ignored
1 = Power Mode is Enabled. In this state, the PID loop is bypassed, and the motor power is taken directly from the mPower register. Encoder position is tracked but ignored.

bit 3 StopGrace
0 = Disabled
1 = Enabled. When this bit is set during a trajectory move, the Gamoto immediately starts decelerating, until completely stopped, using the deceleration rate that is stored in the trajectory. This is only valid when TrajMode is set.

bit 2 VelMode
0 = Disabled
1 = Enabled. When this bit is set, the SetVelocity register is used as a velocity set point. Use this when you want to control the velocity, rather than absolute position. The PID loop will continually add this value to the Position target register. This "moving target" position value causes a constant average velocity. This is only valid when TrajMode is disabled.

bit 1 TrajMode
0 = Disabled
1 = Enabled. When this bit is set, the Gamoto immediately begins following the pre-loaded trajectory. When the trajectory has been completed, this bit is automatically cleared. Poll this bit to find out when the move has been completed.

bit 0 MpwrON
0 = Disabled. Motor will not receive power without this bit set.
1 = Enabled. When this bit is set, the enable pin on the H-Bridge is set, allowing power to flow to the motor. This bit is independent of all other mode settings.

5.6 Mode2 Register

The Mode2 register is shown below. It is a one-byte register, and each bit serves a different function, as shown. Care must be taken to avoid setting incompatible bits, as not every combination is allowed. The allowable modes and combinations are described in the paragraphs below.

Register Name: **MODE2** (Address 0x2D)

R/W 0	R/W 0	R/W 0	R/W 0	R/W 0	R/W 0	R/W 0	R/W 0
reserved	R/C Pulse Enable	Analog Feedback	Step + Direction	115200 baud	SerialShare	MotionDone	Homing
Bit 7	6	5	4	3	2	1	Bit 0

bit 7 Reserved for future use

bit 6 R/C Pulse Input Enable
1 = enabled
0 = disabled

bit 5 Analog Feedback Enable
1 = enabled
0 = disabled

bit 4 Step+Direction Pulse Input Enable
1 = enabled
0 = disabled

bit 3 115200 Baud Rate Enable
1 = enabled
0 = disabled

bit 2 SerialShare Enable
1 = Serial Share enabled
0 = SerialShare disabled

bit 1 MotionDone Enable
1 = enabled
0 = disabled

bit 0 Homing Mode
1 = Homing Mode enabled
0 = Homing Mode disabled

6. Communication Protocols

There are three ways to communicate with the Gamoto: Serial, I^2C bus, or Cricket Bus. All of them require setting/checking the dipswitch settings for configuration.

6.1 Dip Switch Settings

The table below shows the dip switch assignments, and the purpose of each of the switches. Before attempting to use the Gamoto, make sure the switches are set appropriately. The factory default position is all switches in the OFF position.

Dip Switch Assignments

Switch	OFF	ON	Description
1	Cricket Bus	I^2C	Bus selection
2	19200 baud	9600 baud	Serial baud rate
3	0	1	A2 Address bit
4	0	1	A1 Address bit
5	0	1	A0 Address bit

Note that the user must choose either I^2C or Cricket bus, because they share the same I/O pins on the controller. The serial port uses different pins, and can be used regardless of the bus selection position. However, it is not advisable to use the serial port while data is being sent/received on the Cricket or I^2C bus, because some of the same internal registers may conflict in this case.

The A0, A1, and A2 address switches are used to set the Gamoto Address to a value from 0 to 7. The I^2C, Cricket Bus, and Serial protocols use this address to determine which Gamoto is being addressed. The table for setting this address is shown in the I^2C protocol section.

6.2 Communication Protocols: Serial

The normal connection method for serial communications is to have one host connected to one Gamoto. However, the Gamoto is addressable, to allow for a multi-drop communication connection. To connect more than one Gamoto to a single host (PC or MCU), you can simply connect the TX lines in parallel with the other TX lines, and connect the RX lines to the other RX lines. For more detailed instructions on this, refer to this guide available on the Gamatronix website:

http://www.gamatronix.com/gamoto/examples/Serial%20Share%20how-to.pdf

On the protocol level, allowing multiple Gamotos requires that you specify which Gamoto you are speaking to (Gamoto Address). This is specified by setting the dipswitches, as with the I^2C and Cricket protocols. Please refer to the I^2C communication section to see how to set the Gamoto Address (0-7). This Address is added to hex value $AA, and becomes the header byte of the packet. Examples of the different types of transactions are shown below.

For the most common case of RS-232 Serial, with only one Gamoto, simply leave the dipswitch set to the factory positions, and use a header value of $AA.

The checksum is a single unsigned byte, and is calculated by using a simple sum of the preceding bytes, excluding the header and the checksum byte itself. In the case of the checksum totaling more than 255, it rolls over (wraps) as necessary. An example of the formula in Visual Basic is: `CSbyte = (byte1 + byte2 + byte3 + byte4) mod 256`

6.2.1 Example Write $1234 to Kp Register

Header	R W	LEN	RegNum	Data(LSB)	Data(MSB)	CHECKSUM
$AA + (0 to 7)	$03		$22	$34	$12	XX
	<---------- Length ---------->					
	<---------- CHECKSUM ---------->					

The serial protocol is binary-coded, with a header and checksum to help ensure reliable data transfer. The example diagram above shows a two-byte write to the Kp register. The Header byte, which is dependent on the dipswitch setting, is followed by the RW / Length byte. The high bit of this byte is 0 for Writes, 1 for Reads. The lower nibble indicates the length of information to follow, excluding the Checksum byte. The next byte is the target register address, followed by data bytes, and then a checksum. The checksum does not include the header, or the checksum byte itself.

The number of data bytes is flexible, up to a maximum total message size of 8 bytes. This means the maximum continuous bytes you can write to a register location is 4 bytes. This allows you to access any register with a single transaction.

6.2.2 Example Write Response

ACK	CHECKSUM
$41	$41

The reply from the Gamoto is shown above. In place of the header is an ACK byte, which should always be = $41. If this is different, then there was some internal error.

6.2.3 Example Read from Kp Register

Node	R W	LEN	RegNum	NumBytes	CHECKSUM
$AA + (0 to 7)	$82		$22	$02	$A6
			<---------- Len ---------->		
	<---------- Checksum ---------->				

The read is same in structure as the write, with the main difference in the high bit of the RW/Len byte. The high bit is one, indicating a read, and the data following the register number is the number of bytes we want to read. In this case we are requesting two bytes back, and the result is $1234 hex.

6.2.4 Example Read Response

ACK	Data (LSB)	Data (MSB)	CHECKSUM
$41	$34	$12	$87
<---------- Checksum ---------->			

6.3 Communication Protocols: I^2C

To communicate with the Gamoto using I^2C, the first step is to enable I^2C. Turning ON

dipswitch 1 enables this mode. It should be in the ON position for I²C communication. The next step is to set the address bits (dipswitches 3, 4, and 5). If you only have one Gamoto controller, you can leave it at the factory setting of 000 (switches 3,4,5 all OFF). However, if you plan to place more than one Gamoto on the same I²C bus, it will be necessary to set each controller to a different address.

The complete I²C address is constructed from three components: the I²C device type (fixed at "**1001**", with the exception of the broadcast case), the Gamoto address (set by dipswitches 3,4,5), and the Read/Write bit (0=Write, 1=Read).

I²C Slave Address Byte							
1	**0**	**0**	**1**	**A2**	**A1**	**A0**	**R/W**
I²C Device Type				Gamoto Address			Read/Write

Use the following table to find the desired address. A maximum of 8 controllers can be in use on the same bus, due to this I²C addressing limitation. Note that the address used is different, depending on whether you are reading or writing.

SW 3 (A2)	SW 4 (A1)	SW 5 (A0)	Gamoto Address (Binary)	Gamoto Address (Decimal)	I²C Write Address	I²C Read Address
OFF	**OFF**	**OFF**	**000**	**0**	**0x90**	**0x91**
OFF	OFF	ON	001	1	0x92	0x93
OFF	ON	OFF	010	2	0x94	0x95
OFF	ON	ON	011	3	0x96	0x97
ON	OFF	OFF	100	4	0x98	0x99
ON	OFF	ON	101	5	0x9A	0x9B
ON	ON	OFF	110	6	0x9C	0x9D
ON	ON	ON	111	7	0x9E	0x9F
All	All	All	All	Broadcast	0x00	N/A

Bold row represents the factory default configuration.

One the address byte is known (sometimes called the Slave ID), you can begin writing routines to control the Gamoto over the I²C bus.

The last row is the "Broadcast" address, or "General Call", which can be used to send commands to all Gamoto boards simultaneously. This is convenient for starting two or motors at the same time. Keep in mind, however, that it can only be used for commands (writing), not for reading, since you wouldn't want two or more Gamotos responding at the same time.

6.3.1 Example 2-byte Write to Kp register

The basic sequence for a 2-byte write to a register is as follows (shown here, setting register Kp = 0x1234):

```
; I2C Example: 2-byte write to Kp register
; Written in PIC Assembly.  I2C subroutines not shown.

 call I2CStart
 movlw SLAVEID          ; Send control byte (W)
 call I2CWrite
 movlw 0x22             ; RegAddress = Kp
 call I2CWrite
```

```
 movlw 0x34              ; Low byte of data to write
 call I2CWrite
 movlw 0x12              ; High byte of data to write
 call I2CWrite
 call I2CStop            ; Send I2C Stop condition
```

See Appendix B for the I^2C library routines. Additional bytes can be added before the stop condition. They will be written in the next sequential memory location. There is no limit on the quantity of bytes that can be written at one time.

6.3.2 Example 2-byte Read from Kp register

A two-byte register read is as follows:

```
; I2C Example: 2-byte read from Kp register
; Written in PIC Assembly.  I2C subroutines not shown.

 call I2CStart
 movlw SLAVEID           ; Send control byte (W)
 call I2CWrite
 movlw 0x22              ; Set pointer to Kp register
 call I2CWrite

 call I2CRepStart
 movlw SLAVEID+1         ; Send control byte (R)
 call I2CWrite

 call I2CReadwAck        ; First read is with ACK
 movf I2CData,w
 movwf RegDataLSB        ; Store LSB result
 call I2CRead            ; Read without ACK signals last read
 movf I2CData,w
 movwf RegDataMSB        ; Store MSB result
call I2Cstop
```

See Appendix B for the I^2C library routines. Note that the master should not ACK the last read. This signals the end of the read operation. To perform a one-byte read, the one and only read should not be with an ACK, since it is the last read.

6.4 Communication Protocols: Cricket Bus

Before using the Cricket Bus, make sure the bus is enabled, by checking the dip switch settings. If you will be using more than one Gamoto on the same bus, then you also need to set each address differently, so they don't conflict.

The Cricket communication protocol format is shown below. All Cricket messages start with a special 9-bit Cricket Command code. The next byte is the RW/Address byte that tells if the operation is a Read or a Write, and includes the 3-bit unit address of that particular Gamoto controller. The 3 bits allow for up to seven Gamotos on the same Cricket bus. The next byte is the RegNum, or register number, that specifies which register is the target of the read or write. In the case of a write, #Bytes to Write, and Data to be written follows.

Cricket **READ** format:

1	CrktCMD	RW / Address	RegNum	{ data1, data2, …}

Cricket **WRITE** format:

1	CrktCMD	RW / Address	RegNum	#Bytes to Write	{ data1, data2, …}

6.4.1 The Cricket Command Word

1	0	0	1	0	0	1	0
CMD bit	Cricket “Class ID” (Always = $11 for Gamoto devices)						

The best way to think of the Cricket Command Word is that it is always written as $100 + $11 for the Gamoto devices. The $100 signals a command, and the $11 is the Cricket “Class ID” that has been assigned to Gamoto devices. That’s all you need to know to use the Gamoto with Crickets.

If you are implementing a Cricket Bus yourself, using a non-cricket controller, then you may need to understand more of the protocol details. Please refer to the Handy Cricket website for more details on the cricket bus.

6.4.2 RW / Address Byte

R/W	0	0	0	0	A2	A1	A0
Read = 1 Write = 0	Not Used			Broad -cast	Dipswitch 3	Dipswitch 4	Dipswitch 5

The high bit of the RW/Address byte is set to 0 for Writing, 1 for Reading. The lower 3 bits are set to the unit address of that particular Gamoto controller, and must match the dipswitch settings for the unit address.

Broadcast Address

To send a command simultaneously to all Gamotos on the bus, set the broadcast bit. This is the same as using a device address of 8, rather than the usual 0 to 7. This is convenient for starting two motors at the same time (i.e. two wheels on a robot). Note that the broadcast address only works for WRITE operations. Read operations would cause conflicting responses.

6.4.3 RegNum

The register number corresponds to the starting address of the register you wish to write/read to/from. Please note that many registers have fractional components, so you need to pay close attention to the register map to make sure you are accessing the correct starting point of the register.

6.4.4 Data

The data following a write command can be a maximum of four bytes. After each byte is written, the internal pointer is incremented, allowing sequential writes to a range of register

bytes. When reading using the cricket bus, a dummy data byte must be sent in order to read each byte. So to read a three-byte register, you must send the CricketCMD byte, RW/Address byte, RegNum, then a dummy data byte. Read the first byte. Send a second dummy byte, then read the next byte. Send a third dummy byte, then read the final byte.

6.4.5 Cricket Logo Example: Reading and Writing Registers

Using the Handy Cricket to control the Gamoto is very easy. Below is an example of using Cricket Logo to read and write to 8-bit Gamoto registers. The command to send a byte out the Cricket bus is **bsend**, and to read a byte is **bsr**. Every bsr command must be followed by a dummy data byte, which is used to trigger the read operation.

The Gamoto has been assigned the Cricket "Class ID" of 17, or $11 hex. All Gamotos respond to the class ID. The first byte to send is the command bit ($100) + $11 = $111. Then they look at the next byte, the "adr" or address, to see if the command is for them. This number must match the address set by the dipswitches on the Gamoto.

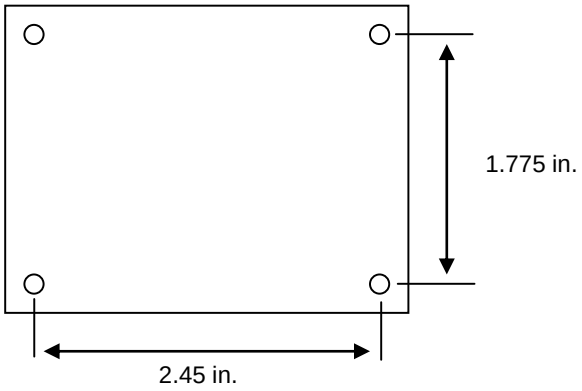
```
; Write to an 8-bit Gamoto register
to gxSetReg8 :reg :val :adr
bsend $111
bsend :adr
bsend :reg
bsend low-byte :val
end
```

```
; Read from an 8-bit Gamoto register
to gxReadReg8 :reg :adr
bsend $111
bsend :adr + 128
bsend :reg
output bsr 1
end
```

A full set of Cricket library routines for controlling the Gamoto is available at the Gamatronix web site. By pasting these routines into your Cricket program, you can be controlling the Gamoto in no time!

7. Mechanical Specifications

The dimensions of the Gamoto board mounting holes are shown in the figure below. Be careful when mounting the board to protect the bottom of the board from contact with metal surfaces that could short out the signals. The board itself measures 2.75 in. x 2.075 in. The mounting holes are 0.15 inch diameter, large enough for 4-40 or 6-40 screws.



8. Electrical Considerations

When designing your control system, one of the first considerations is the power supply design. In general it is desirable to separate digital control power from noisy, high-current motor power. The Gamoto board allows this separation by having two separate connectors. J8 is for logic power input, and J2 is for Motor power connection. However, these supplies are isolated on the board by a voltage regulator, so it is also possible to use one power connector for both, and tie them together using jumper JP1.

Separated power inputs

When using two separate power inputs, you can take advantage of higher motor voltages, from 12V up to 55V for your motor. You can also shut off or disconnect motor power without resetting the logic side of the motor board. In this configuration the logic power can be from 7.5V to 16V DC.

Combined power inputs

To combine power inputs, install jumper JP1. With JP1 installed, only one connector (J2) must be used to supply power. DO NOT INSTALL JP1 WITH POWER CONNECTED TO BOTH CONNECTORS! When combining the power inputs, you are limited to a more narrow range of allowable voltages. The acceptable range for combined power input is 12V – 16V. The advantage is a simpler cabling/connector design, and one switch can control the whole system.

REV E BOARDS ONLY*: One note about the fuse: The fuse is only connected to the J2 connector; so if you are using a single power connection, use J2, not J8. Rev F and later boards do not have this problem.*

Current Draw

The typical standby current flow of the logic circuits is 40mA without encoders connected. Depending on the type of encoders used, this will increase to 80 to 110mA. Note that with

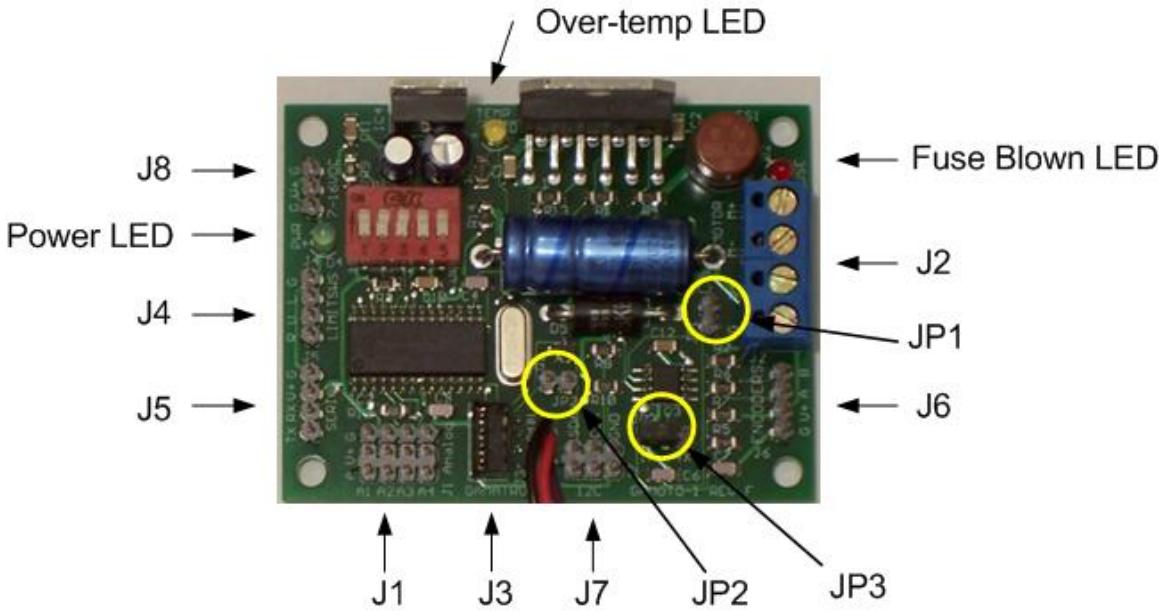
high-current encoders and high logic voltage supply (i.e. 16VDC), the 5V regulator will get quite warm and a heat-sink is highly recommended.

Current draw for the motor side of the circuit is entirely dependent on the motor coil resistance and the torque applied on the motor shaft. An easy way to estimate current is to measure the motor winding resistance, and divide this into the motor voltage you plan to use. Make sure the estimated current is less than 3 Amps before connecting it to the Gamoto.

An example calculation is as follows: Motor winding resistance measures 6 ohms, and you plan to use a 12V battery. Since batteries usually charge higher than their nominal voltage, let's assume 13 volts for the calculation. So current = 13 / 6 = 2.17 Amps. This is less than 3 A, so it should work fine with the Gamoto.

9. Connector Pinouts

This section shows connector pin assignments and electrical details required for interfacing the Gamoto to your application. The connectors are labeled JP1 to JP10, as printed on the PC board's silkscreen.



9.1 LED Indicators

The Gamoto board has three LED indicators. A green power LED (D4) lights when logic power is present. A yellow Over-Temp LED (D3) lights when the H-Bridge indicates it is in temperature shutdown mode. A red "Fuse Blown" LED (D2) lights when the fuse is removed or blown.

9.2 Fuses

There is one removable fuse on the Gamoto, labeled FS1, in the upper right corner of the board. If this fuse is damaged or removed, the red fuse LED will light. The Gamoto ships with 5A fuse in this position, but you can change this value if you like. The ordering information for additional fuses is shown here:

Fuse Type	Digikey P/N
1.0 Amp, Fast-acting	WK3048BK-ND
1.25 Amp, Fast-acting	WK3050BK-ND
1.6 Amp, Fast-acting	WK3053BK-ND
2.0 Amp, Fast-acting	WK3057BK-ND
2.5 Amp, Fast-acting	WK3058BK-ND
3.15 Amp, Fast-acting	WK3024BK-ND
4.0 Amp, Fast-acting	WK3062BK-ND
5.0 Amp, Fast-acting	WK3063BK-ND

9.3 Jumpers

9.3.1 JP1 Motor Power Jumper

This jumper bridges the Motor Power supply with the Logic Power supply. See section 8 (Electrical Considerations) for details and precautions about using this jumper.

9.3.2 JP2 Cricket Power jumper

This jumper bridges the logic power for the Gamoto to the power on the Handy Cricket, if you have a Cricket connected to the cricket cable. This allows you to use either only the Handy Cricket's power supply, or only the Gamoto power supply. Care should be take not to use the jumper when both supplies are present.

9.3.3 JP3 Encoder 1X/4X Setting (Rev F and later boards only)

This jumper selects between 1X and 4X encoding for the quadrature encoders. A setting of 4X allows a 500 count encoder to have 2000 pulses per revolution, by triggering on the pulse edges, rather than each complete pulse cycle. This feature is only available on rev F and later boards.

9.4 J1: Analog Inputs

J1	Row	Analog Inputs
G	1	Ground
V+	2	5 VDC output. Can be used to supply power to external sensor.
A	3	Analog voltage input, 0 – 5VDC

This connector is used to connect up to four analog inputs. For each of the four channels (A1 – A4), a separate power and ground pin is available, making it easy to keep cabling simple, and to provide power to an analog sensor, such as the Sharp GP2D12 sensor.

NOTE: Analog Channel 4 (pin A4) can be used to connect a Home Switch, if the Homing mode is enabled (see Homing Mode description).

NOTE: Analog Channel 2 (pin A2) can be used as an interrupt output, or "MotionDone" pin, if this is enabled by configuring Mode2. In this case, it becomes a normally high output pin, and goes low during a trajectory and high when a trajectory is finished.

NOTE: Analog Channel 1 connector can be used for the Analog Feedback feature. This allows the use of a potentiometer or analog voltage in place of a quadrature encoder.

NOTE: Analog Channel 0 is not available on this connector, because it is dedicated to reading motor current. It is connected to the H-bridge on the Gamoto board.

9.5 J2: Motor Power Input and Output

J2	Pin	Motor Power Input. This supplies power for the Motor.
M+	1	Output to Motor winding. Reverse these to change motor direction
M-	2	Output to Motor winding. Reverse these to change motor direction
V+	3	+12 – 55 VDC* input. Current consumption up to 3A continuous, 6A peak
G	4	Ground

* Maximum motor input voltage will be limited to 16 volts if jumper JP1 is used, tying together the logic and motor voltage inputs

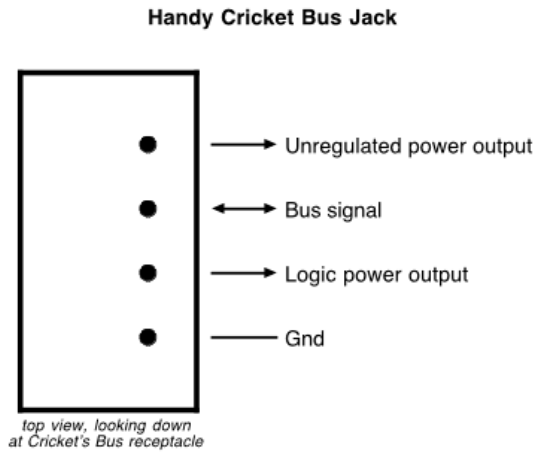
This connector is used both to supply motor power and to distribute power to the motor. G and V+ should be connected to a battery or other high-current voltage source. Pins M+ and M- should be connected to the motor windings. The polarity of these terminals is usually determined by trial and error. If the motor operates in the wrong direction, reverse these leads.

IMPORTANT NOTE: MOTOR POWER MUST BE AT LEAST 12 VOLTS FOR THE H-BRIDGE TO WORK PROPERLY. LOWER VOLTAGES WILL CAUSE STRANGE BEHAVIOR THAT IS DIFFICULT TO TROUBLESHOOT, SO ALWAYS CONFIRM MOTOR VOLTAGE IN CASE OF ODD BEHAVIOR.

If you do not want to use 12V or more because your motor is rated for a lower voltage, then refer to the register descriptions on pwrLimit. This will allow you to use a lower voltage motor.

9.6 J3: Cricket Bus connector

J3	Pin	Cricket Bus Connector.
G	1	Ground
Vcc	2	Regulated 5VDC power supply. Use jumper JP 12 to disconnect this
Bus	3	Bus data line. This is normally high, low when active, or during init signal
V+	4	Unregulated voltage supply



This port can used to connect the Gamoto to a Handy Cricket or other Cricket Bus-enabled device. A second optional "pigtail" connector is hooked in parallel to this one, for easy daisy-chaining of bus devices. For more details on the Cricket Bus connector and protocol, see http://www.handyboard.com/cricket/tech/bus.shtml

9.7 J4: Limit Switch Inputs and Reset

J4	Pin	Limit Switch Inputs and Reset line
G	1	Ground
LL	2	Lower Limit switch input / **Step** signal input
UL	3	Upper Limit switch input / **Direction** signal input / **R/C pulse** input
Reset	4	Reset line for Gamoto processor. Momentarily pull this line low to reset Gamoto.

This connector is used to add limit-switch interlocks to your control system. By pulling the Lower Limit input low, clockwise motion of the motor will be disabled; until the line is released (there is an internal pull-up resistor in the Gamoto). If the Upper Limit input is pulled low, counter-clockwise motion will be disabled, until the line is released. This allows a mechanism of preventing travel beyond a mechanical limit, by adding limit switches at each end of the travel.

When in Step + Direction mode, pins 2 and 3 are used for Step + Direction, respectively. When in R/C Pulse mode, pin 3 is used for the R/C pulse input, which allows connection of the standard R/C cable pin-out (Gnd, 5V, signal) on pins 1,2,3. Connecting +5V to pin 2 is not needed, but has no ill effect, and is convenient for this mode of operation (**see warning below**).

NOTE: When connecting an R/C signal cable to J4, remember that all pins have a 5V maximum. If your servo cable carries more than 5V on the middle pin (pin 2, LL), it will damage the Gamoto, so you must not connect this pin. In this case it would be better to remove the pin or wire for this signal, and connect only GND and the 5V R/C pulse signal.

There is also a reset pin available to allow an external processor to electrically reset the Gamoto, by pulling the reset line low momentarily.

9.8 J5: Serial Interface

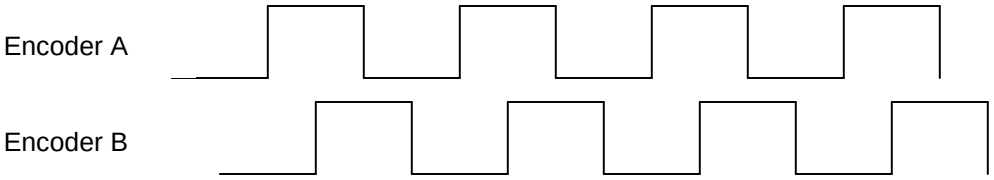
J5	Pin	Serial Interface connector.
1	G	Signal Ground
2	Vreg	Regulated 5 Volt supply output, available to power a serial level adapter
3	RX	Serial Receive line, 5V logic levels
4	TX	Serial Transmit line, 5V logic levels

This connector is used for controlling the Gamoto from a serial host, such as a microcontroller (MCU) or PC. When communicating using this port, use the serial protocol as described in communication section of this manual. NOTE: You cannot directly connect a PC serial port to this connector, because the logic levels are 5V levels, not RS-232 or RS-485 levels. A serial transceiver chip, such as the Maxim MAX232 must be used in this case. Either RS-232 or RS-485 transceivers may be used, depending on the application. If RS-485 is chosen, you must use a transceiver capable of automatically enabling the driver upon transmission ("AutoDirection" feature or similar name). Two examples of this type of chip are the Maxim MAX13487E and MAX13488E devices. See the Gamatronix website (www.gamatronix.com) for sources for off-the-shelf serial adapter cables, to allow easy connection to a PC.

9.9 J6: Encoder Inputs

J6	Pin	Quadrature Encoder inputs
G	1	Ground
Vreg	2	Regulated 5 VDC output. Supplies power to LED for encoder.
A	3	Quadrature Encoder input signal, Phase A
B	4	Quadrature Encoder input signal, Phase B

This connector is used to power the encoders and to receive the encoder input signals. The two inputs, A and B, should be out of phase with each other, to indicate motor direction, as shown below:



Please note that if a normal LED is connected directly to this power supply, a current-limiting resistor must be used, to avoid damaging the LED. Most commercial encoder modules have these resistors included, and some LEDs have current limiting built in. Check the encoder or LED datasheet to be sure.

9.10 J7: I^2C Interface

J7	Pins	I^2C Communication Interface
SDA	1,2	I^2C Data signal. This is an open-collector 5V logic signal, with pull-up resistor.

CLK	3,4	I^2C Clock signal. This is an open-collector 5V logic signal, with pull-up resistor.
G	5,6	Ground

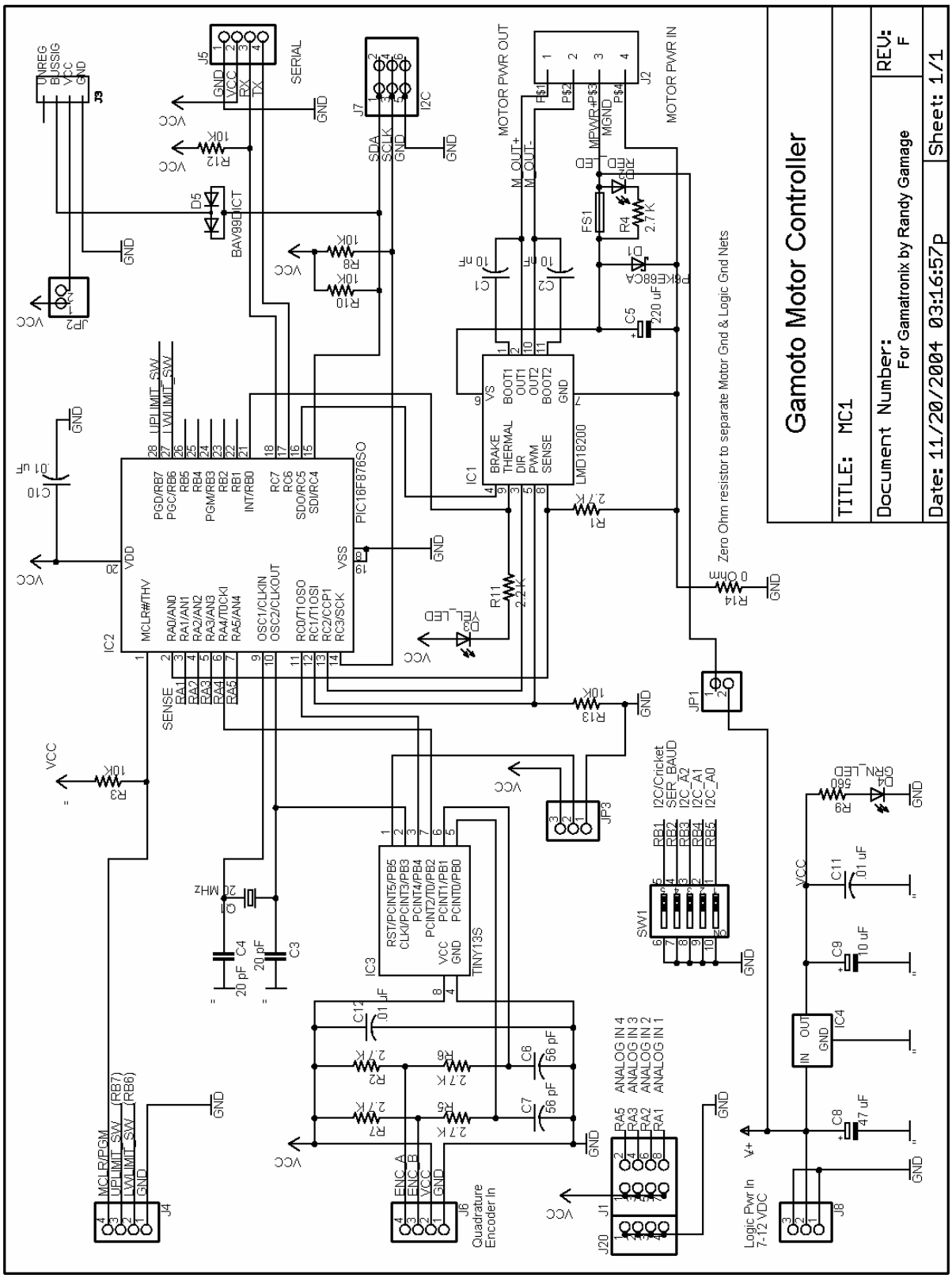
This connector is used to control the Gamoto from an I^2C Master device, such as a microcontroller (MCU). The clock (CLK) and data (SDA) lines are held high by pull-up resistors on the board, and are pulled low when active. Note that the two connectors are wired in parallel, for easy daisy-chaining of I^2C devices.

9.11 J8: Logic Power Input

J8	Pin	Logic Power Input. This supplies power for the digital components.
G	1	Ground
V	2	+7.5 – 16 VDC. Typical current consumption is 40 mA @ 12V
G	3	Ground

Although this is a three-position connector, only one ground connection is necessary. The third pin has been added to help prevent accidentally reversing the input power. We recommend using a three-pin connector for power, because it allows the user to connect in either orientation without risk of damaging the board**. WARNING: There is NO internal protection against reverse-polarity, so if power is connected backwards, the 5V regulator WILL be permanently damaged.** The good news is that this is a commonly available part, and not too difficult to replace if you have a solder iron and some electronic experience. The Digikey part number is LM340T-5.0-ND, but many substitutes can be used, such as the LM7805.

10. Schematic Diagram



11. Appendix A: Factory Default values

Below are the factory defaults of the flash registers. These values can be restored at any time by writing to the command register, FactoryRst.

Register	Factory Default Value
Kp	500
Ki	3
Kd	200
iLimit	5000
dS	10
Mode	1
pwrLimit	255
Mode2	0

To change the value that these registers will have at power-up, simply set them to the desired values, and then write to the command register SaveParms to save them to flash memory. Now, every time you power up, the values you programmed will be set. To revert back to the original factory values at any time, write to the FactoryRst command register.

12. Appendix B: I²C Subroutines for PIC Assembly

The following routines can be used with a PIC microcontroller to implement an I²C Master. The sample code is for a 20MHz clock, but can easily be adapted to other clock speeds. Note that for communicating with the Gamoto, 400 kHz is the maximum I²C speed that should be used.

```
;Slave address of I2C device to whom we are talking
#DEFINE SLAVEID 0x90        ; Set this for your device

; ********************************************************************
; MACRO DEFINITIONS
; Generic PIC Assembly macro definitions
;
ifpos   macro arg1
  btfss arg1,7              ;Test if argument is positive (high bit clear)
  endm
ifneg   macro arg1
  btfsc arg1,7              ;Test if argument is negative (high bit set)
  endm

bank0   macro
  bcf STATUS,RP1
  bcf STATUS,RP0
  endm

bank1   macro
  bcf STATUS,RP1
  bsf STATUS,RP0
  endm

bank2   macro
  bsf STATUS,RP1
  bcf STATUS,RP0
  endm

bank3   macro
  bsf STATUS,RP1
  bsf STATUS,RP0
  endm
;
;=================================================
; I2C Routines (using H/W I2C Peripheral)
;=================================================
I2CInit:
              ;NOTE: I2C Pins must already be set to be INPUTS
  movlw 0x28                ; Set mode to I2C Master, enable I2C
  movwf SSPCON
  bank1
  clrf SSPCON2^0x80         ; Clear status flags
  movlw 49                  ; Set speed to 100kHz w/20MHz clock
  movwf SSPADD^0x80
  bsf SSPSTAT^0x80,SMP      ; Disable slew rate control, set for 100kHz
  bcf SSPSTAT^0x80,CKE      ;  Set levels to I2C (set if you want SMBus
levels)
  bank0
  bcf PIR1,SSPIF            ; Clear SSPIF interrupt flag
  bcf PIR2,BCLIF            ; Clear bus collision flag
  return
```

```
I2CWaitForIdle:
 bank1
I2C_WFI:
 movf SSPCON2^0x80,W       ; Check all busy bits
 andlw 0x1F
 skipz
 goto I2C_WFI
 ifset SSPSTAT^0x80,R_W
 goto $ - 1
 bank0
 return

I2CStart:
 call I2CWaitForIdle
 bank1
 bsf SSPCON2^0x80,SEN             ; Initiate Start
 bank0
 return

I2CRepStart:
 call I2CWaitForIdle
 bank1
 bsf SSPCON2^0x80,RSEN            ; Initiate Repeated Start
 bank0
 return

I2CStop:
 call I2CWaitForIdle
 bank1
 bsf SSPCON2^0x80,PEN             ; Initiate stop
 bank0
 return

I2CRead:
 call I2CWaitForIdle
 bank1
 bsf SSPCON2^0x80,RCEN            ; Initiate receive
 bank0
 call I2CWaitForIdle
 movf SSPBUF,W
 movwf I2CData
 call I2CWaitForIdle
 bank1
 bsf SSPCON2^0x80,ACKDT           ;  Don't  send  an  ACK  (EEPROM  doesn't
require it)
 bsf SSPCON2^0x80,ACKEN           ; Initiate ACK sequence
 bank0
 return

I2CReadwAck:
 ; Same as I2CRead, but we send an ACK this time
 call I2CWaitForIdle
 bank1
 bsf SSPCON2^0x80,RCEN            ; Initiate receive
 bank0
 call I2CWaitForIdle
 movf SSPBUF,W
 movwf I2CData
 call I2CWaitForIdle
 bank1
 bcf SSPCON2^0x80,ACKDT           ; Send an ACK this time
 bsf SSPCON2^0x80,ACKEN           ; Initiate ACK sequence
```

```
  bank0
  return

I2CWrite:
  movwf I2CData       ; Save input value
  call I2CWaitForIdle
  movf I2CData,W
  movwf SSPBUF
  call I2CWaitForIdle
  ; Can capture ACK return value here (in SSPCON2, ACKSTAT) if desired
  return
```

13. Appendix C: FAQs

Frequently Asked Questions

1. **What if my motor doesn't have encoders, or I don't want to use encoders?**

   No problem. Set the mode to Power mode, and use the mPower register to manually control power to the motor.

2. **I want to use a 6-volt motor, but the spec sheet says minimum 12 volts. Am I out of luck?**

   No! Just set the max power to 50%, and there will never be more than 6V of power to your motor, even though you are running off a 12 Volt battery. Similar power limiting can be done for any combination of battery levels and motor limitations.

3. **My Gamoto was working fine, but now the motors won't run. What's wrong?**

   Most likely your battery has run down to less than 12 Volts. Double check the voltage and make sure it reads at least 12V under load.

4. **My Gamoto board is dead. The green power light does not light when power is connected. What's wrong?**

   Most likely, the 5V regulator has been damaged, either by reversed polarity or a short of some kind. Replace the 5V regulator.

5. **Is the Gamoto firmware field-upgradeable?**

   Yes, it is. Please contact us at sales@gamatronix.com for details to upgrade your Gamoto firmware.

6. **A red LED is lit on the board. My Gamoto is communicating, but the motors are dead. I've checked the voltage levels and they're fine. What's wrong?**

   Your fuse has blown or is missing. Remove and check it for continuity. See the section in the User's Manual on fuses to find ordering information.

7. **Where can I ask more questions, and share experiences with other users?**

   Join the Gamatronix Yahoo forum. The web page is at:
   http://groups.yahoo.com/group/gamatronix